CALIFORNIA WETLAND AND RIPARIAN GEOGRAPHIC INFORMATION SYSTEM PROJECT

Final Report
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Prepared By:

Ducks Unlimited, Inc.

For:

California Department of Fish and Game, Natural Heritage Division
California Wildlife Conservation Board
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4. ABSTRACT

This report describes a California Wetland and Riparian GIS database developed by Ducks Unlimited under contract with the California Department of Fish and Game (CDFG), the Wildlife Conservation Board (WCB), and the U.S. Bureau of Reclamation. The goal of this project is to develop a Wetland and Riparian GIS database for four key regions in California: 1) the Sacramento Valley, 2) the San Francisco Bay and Delta, 3) the San Joaquin Valley, and 4) the South Coast to support cooperative conservation planning and wetland resource protection efforts of state, federal, and local governments and private organizations. For the first three regions, Landsat Thematic Mapper satellite imagery was processed to map land cover classes from three broad categories: wetlands, agriculture, and uplands. The imagery was stratified into these three categories using a combination of ancillary datasets and a same year winter image classified to identify winter inundation. This stratification reduced confusion between spectrally similar classes (for example, rice and emergent wetlands) and helped refine the spectral signatures. Each strata of imagery was then classified into more detailed classes using a combination of supervised and unsupervised classification techniques. Field data, ancillary data, and aerial photographs were used to identify training sites and label spectral clusters. Finally, GIS modeling was performed using ancillary data (National Wetlands Inventory, hydrography, and winter inundation) to provide additional detail to the classification results. For the fourth region, the South Coast, U.S. Fish and Wildlife Service National Wetlands Inventory data were assembled and summarized.

5. EXECUTIVE SUMMARY

In 1993, Governor Pete Wilson established a Wetlands Policy which identified the need for a comprehensive wetlands inventory. In response to this need, California Department of Fish and Game (CDFG) Natural Heritage Division and the Wildlife Conservation Board (WCB) entered into an agreement with Ducks Unlimited, Inc. (DU) in the fall of 1994 to generate a Wetlands and Riparian GIS inventory using satellite imagery for three key regions in California: 1) the Sacramento Valley, 2) the San Francisco Bay and Delta region, and 3) the north San Joaquin Valley. In addition, National Wetlands Inventory data was summarized for the South Coast region. A second agreement with the U.S. Bureau of Reclamation (BOR) provided funding for mapping the remainder of the Central Valley--the south San Joaquin Valley and the Vina Plains region. The resulting database, developed by DU, Pacific Meridian Resources, CDFG, WCB, and BOR staff, is intended to support cooperative conservation planning and wetland resource protection efforts of state, federal, and local agencies and private organizations. The methods used to produce the Wetlands and Riparian GIS database are repeatable and allow for rapid, cost effective updates to this database in the future.

Landsat Thematic Mapper satellite imagery was chosen as the primary source data for this mapping project. Satellite imagery offers a number of advantages for a project of this scope. It is a cost effective data source for regional mapping, can be processed using automated mapping techniques, and is collected on a repeat cycle, providing a standardized data source for future database updates. In addition, Thematic Mapper imagery includes a mid-infrared band which is sensitive to both vegetation and soil moisture content and has proven useful in identifying water and wetland features.

Because of the dynamic nature of the wetlands in the Central Valley, a multitemporal approach was implemented to take advantage of the unique information recorded on satellite imagery from both the summer and winter seasons. Ten Landsat Thematic Mapper scenes--a summer and winter scene from three scene locations--and a SPOT scene were acquired to cover the project area. Imagery collected during the summer growing season was processed to identify wetland emergent vegetation and other landcover classes while an image collected during the previous winter (or nearest available winter date) was used to identify areas of winter standing water, providing a means to separate the drier wetlands from upland grasses and to separate permanently flooded and seasonally flooded wetland emergents.

The classification scheme for this mapping project was developed to provide information for wetland planners and to take advantage of the information from the two dates of imagery. This classification scheme was modeled in part after the Cowardin System and the National Oceanic and Atmospheric Administration Coastal Change Analysis Program (NOAA C-CAP) protocols which were designed for use with satellite imagery. The classes were organized in a hierarchical manner to facilitate the integration of more detailed information from higher resolution data sources. The classification scheme was reviewed and approved by the Project Technical Advisory Team.

Classification Scheme

1. Open Water
2. Emergent Wetlands / Flats
    - 2.1 Estuarine Emergents
        - 2.1.1 Seasonally Flooded Estuarine Emergents
        - 2.1.2 Permanently Flooded Estuarine Emergents
        - 2.1.3 Tidal Estuarine Emergents
    - 2.2 Palustrine Emergents
        - 2.2.1 Seasonally Flooded Palustrine Emergents
        - 2.2.2 Permanently Flooded Palustrine Emergents
    - 2.3 Flats
3. Agriculture
    - 3.1 Flooded Agriculture
    - 3.2 Seasonally Flooded Agriculture
    - 3.3 Non-Flooded Agriculture
    - 3.4 Orchards / Vineyards
4. Woody
    - 4.1 Riparian Woody
    - 4.2 Non-Riparian Woody
5. Grass
6. Barren
7. Other

Image processing techniques were used to classify the satellite images to produce the final GIS data layer. Initially, the winter imagery was classified to produce a digital map of winter standing water. This winter water data layer was then used along with digital National Wetlands Inventory (NWI) data and Department of Conservation Farmlands Mapping and Monitoring data to stratify the summer image into three broad landcover classes: wetlands, agriculture, and non-agriculture uplands. This stratification was done to reduce confusion between spectrally similar wetlands and uplands. The winter water data layer (known as "winter wet") was included in the stratifying to pick up any potential wetlands that the NWI data may have missed. After stratification, each image strata was classified separately using a combination of supervised and unsupervised classification techniques. Field data, aerial photography, and other ancillary data sources were used to assist in the labeling of clusters.

After each of the strata were spectrally classified, they were mosaicked together and three GIS modeling steps were performed to further refine the classification. First, modeling with the winter wet data layer was performed to label seasonally flooded agriculture and seasonally flooded wetlands. Next, NWI data were used to apply wetland system labels (Estuarine vs. Palustrine) and Baylands Atlas data were used to apply a secondary label (Tidal vs. Non-tidal) to the spectrally classified wetlands. Finally, GIS modeling was performed to identify a riparian woody class. A mask of potential riparian areas was generated using NWI data, CDFG River Reach hydrography data, the CDFG Natural Diversity Data Base, and a manually digitized floodplain coverage. This mask was overlaid over the classified map and any non-agricultural woody areas falling within the mask were included in the riparian woody class.

Because of the use of multiple dates of imagery, the seasonal nature of many of the classes, and a lack of near-date aerial photography, it was not possible to perform a rigorous, quantitative accuracy assessment on the classified map layer. Instead, draft maps were produced and distributed to reviewers solicited from various state and federal agencies and private organizations. The comments from the reviewers served as a qualitative accuracy assessment and identified problem areas that were addressed during the final editing phase.

The final product of this project consists of a Wetland and Riparian GIS database for the Sacramento Valley, the Bay and Delta regions, and the San Joaquin Valley. The database provides information that is relatively uniform in coverage, date, and scale and is useful for statewide and regional level planning efforts. For finer level planning, the database will likely best be used as a general baseline to focus gathering of more detailed information and to fill gaps until such information can be assimilated.

6. BACKGROUND

Agricultural and urban development in California have seriously impacted the state's wetland resources. U.S. Fish and Wildlife statistics indicate that of the original 5 million acres of wetlands in the Central Valley of California, only 319,000 remain (Gilmer et al., 1982; Frayer et al., 1989). Central Valley agricultural lands support 60% of the Pacific Flyway's waterfowl (20%-30% of North America's total waterfowl). Several state and federal resources programs have a need for an up-to-date wetlands inventory to quantify the location and extent of wetlands and to aid in determining the status and health of California's wetlands. Although a number of site-specific (i.e. county level, etc.) inventory projects have been initiated, there is little in the way of a comprehensive, statewide wetlands inventory. The U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) program has delineated wetland types at a scale of 1:24,000 using aerial photography ranging in date from the early 1970's to the mid 1980's. However, this data is outdated and often does not reflect the current intensive management practices on state and federal wildlife refuges.

In 1993, Governor Pete Wilson established a Wetlands Policy which identified the need for a comprehensive wetlands inventory as a high priority. Subsequently, the California Resources Agency began to investigate optimal techniques for establishing an up-to-date, statewide inventory of wetlands. A project completed by Ducks Unlimited, Inc. (DU) and California Department of Fish and Game (CDFG) in 1990 used satellite imagery from the winter season to inventory the amount of flooded waterfowl habitat throughout the Central Valley (Kempka et al., 1990). This project demonstrated satellite image processing techniques can provide a cost effective and repeatable inventory method for covering large regional areas such as the Central Valley of California. Based on the results of this project, recommendations were made to use satellite imagery from two seasons within the same year to assess the status of wetlands in the Central Valley. A winter season (November-December) image was proposed to determine the maximum extent of standing water. A second, summer season image was recommended to determine wetland types during the growing season.

In the fall of 1994, CDFG Natural Heritage Division, the Wildlife Conservation Board, and Ducks Unlimited, Inc., entered into an agreement to generate a Wetlands and Riparian GIS Inventory. The allocated funding provided for mapping of approximately two-thirds of the Central Valley, the San Francisco Bay region, and the Sacramento/San Joaquin River Delta. . Mapping of the remainder of the Central Valley, including the south San Joaquin Valley and the Vina Plains region in the northern Sacramento Valley, was completed in 1996 using the same methods and equipment with funding from the U.S. Bureau of Reclamation. The resulting product, developed by DU, Pacific Meridian Resources, CDFG, WCB, and BOR staff, is intended to support state, federal, local, and private wetland conservation planning efforts. The entire 10.3 million acre region was mapped using satellite classification techniques in less than 2.5 years. The methods used are repeatable and will allow for rapid, cost effective updates to this database in the future.

7. OBJECTIVES

The goal of this project is to develop a Wetland and Riparian GIS database for four key regions in California: 1) the Sacramento Valley, 2) the San Francisco Bay/Delta, 3) the San Joaquin Valley, and 4) the South Coast to support cooperative conservation planning and wetland resource protection efforts of state, federal, and local governments and private organizations.

8. PROJECT DESIGN

Landsat Thematic Mapper satellite imagery was selected as the primary data source for this mapping project. Considerable thought went into the selection of the dates of imagery to use. The wetlands of the Central Valley are very dynamic, due in large part to the highly manipulated hydrology of the Valley. Snowpack accumulated in the mountains during the winter months is collected in reservoirs where it is distributed to irrigation districts. These irrigation districts in turn provide water to large expanses of agriculture as well as the wildlife refuges and preserves which contain most of the remaining wetlands. Land managers irrigate and drain the land at different times of year depending on the crop or wetland management scheme. Wetlands are most easily spectrally distinguished from upland land covers by the presence of water or moist soil. But the variety of wetland management schemes practiced in the Valley makes the selection of an optimal date of imagery for wetlands identification difficult.

Table 1 illustrates the flooding cycles of some common wetland management schemes used in the Central Valley. Permanently flooded ponds contain water throughout the year and are usually dominated by dense stands of tule and cattails (Heitmeyer et al., 1989). In areas managed for summer water, ponds are flooded from around June through March or April. Ponds managed strictly for watergrass are flooded from October to mid-spring and are irrigated at least once during the summer. Seasonally flooded habitats are flooded from early fall (usually just prior to hunting season) through early spring or early summer when the water is drawn down or evaporates. The timing of the spring draw down varies depending on the type of vegetation that is being encouraged. It would appear that a winter date of imagery would provide most effectively for the identification of wetlands, however this is not necessarily true. Vegetation in the seasonally flooded habitats and watergrass production areas is generally completely inundated during the winter, making the spectral separation of wetland vegetation from open water difficult or impossible. Yet in the summer, many of these seasonally flooded wetlands are dry and thus lack the soil moisture necessary to spectrally identify them as wetlands. Again, given these parameters, the selection of a single, optimal date of imagery for wetlands identification is difficult (Kempka and Kollasch, 1990).

Table 1. Flooding Regimes of Central Valley Wetland Management Schemes (Heitmeyer et al., 1989).

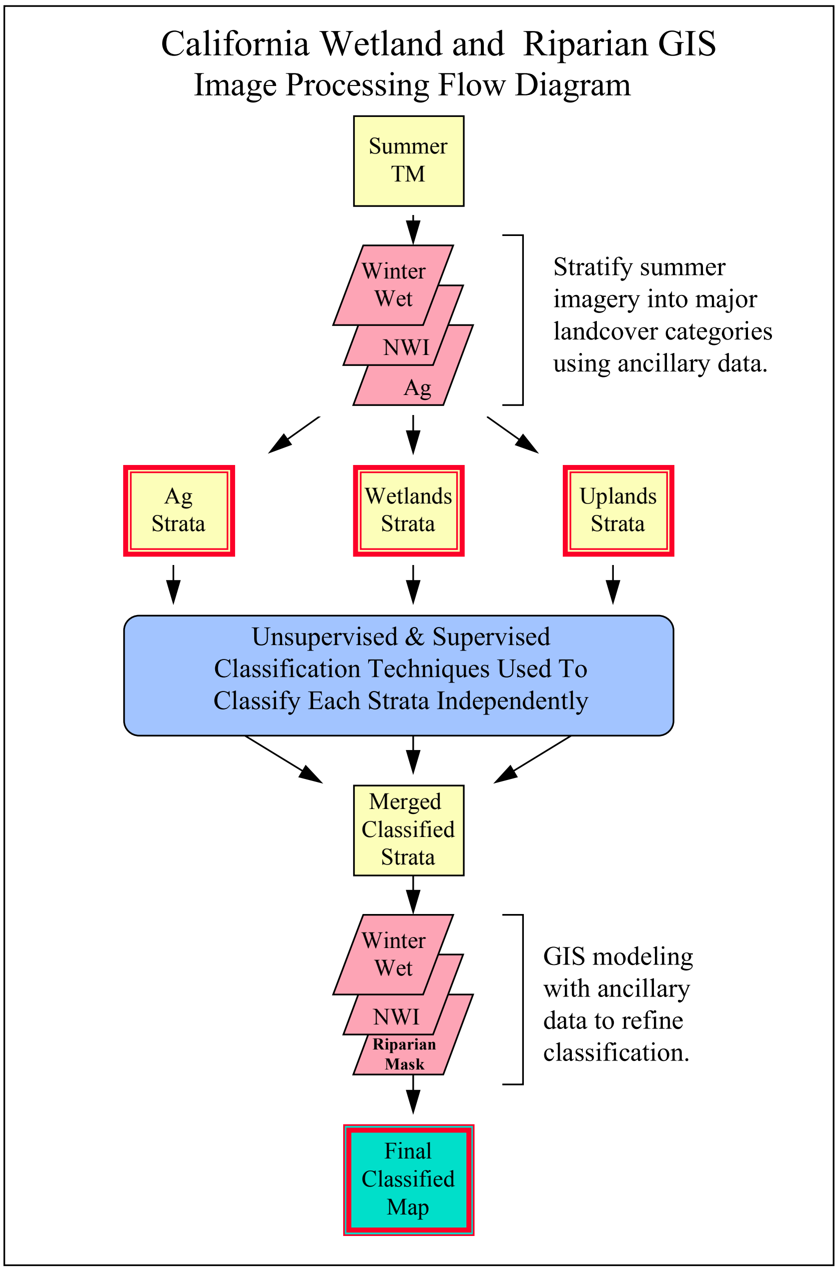
HABITAT TYPE	MONTH											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Permanently Flooded Ponds	X	X	X	X	X	X	X	X	X	X	X	X
Summer Water Management	X	X	X	X		X	X	X	X	X	X	X
Seasonally Flooded Habitats	X	X	X						X	X	X	X
Watergrass Management	X	X	X	X		X				X	X	X

To overcome this difficulty, a multitemporal approach was adopted to take advantage of the unique information recorded on satellite imagery from both the summer and winter seasons. A summer image was processed to identify wetland emergent vegetation and a winter image was used to identify areas of winter flooding, thus providing a means to separate drier wetlands from upland grasses and permanently flooded wetland emergents from seasonally flooded wetland emergents.

A second challenge was to separate wetlands from various upland classes with similar spectral properties. For example, emergent wetland grasses in standing water are spectrally indistinguishable from emergent rice during much of the summer growing season. Similarly, riparian woody vegetation cannot always be distinguished from non-riparian woody vegetation or orchards based on the spectral properties alone. To separate these classes, it was necessary to incorporate ancillary GIS datasets into the classification process. Initially, digital National Wetlands Inventory (NWI) data, data from the Department of Conservation Farmland Mapping and Monitoring program, and a standing water data layer produced by classifying the winter image were used to stratify the imagery into three broad classes: wetlands, agriculture, and non-agricultural uplands. The winter water data layer was included to pick up any potential wetlands that the NWI data may have missed.

The three image strata--wetlands, agriculture, and uplands--were then classified separately based on the spectral properties within each image. Following the classification process, GIS modeling was performed to add information to the final database. Digital NWI data, CDFG River Reach hydrography files, and a CDFG Natural Diversity Data Base riparian coverage were used for this modeling. A flow diagram of the project design is shown in Figure 1.

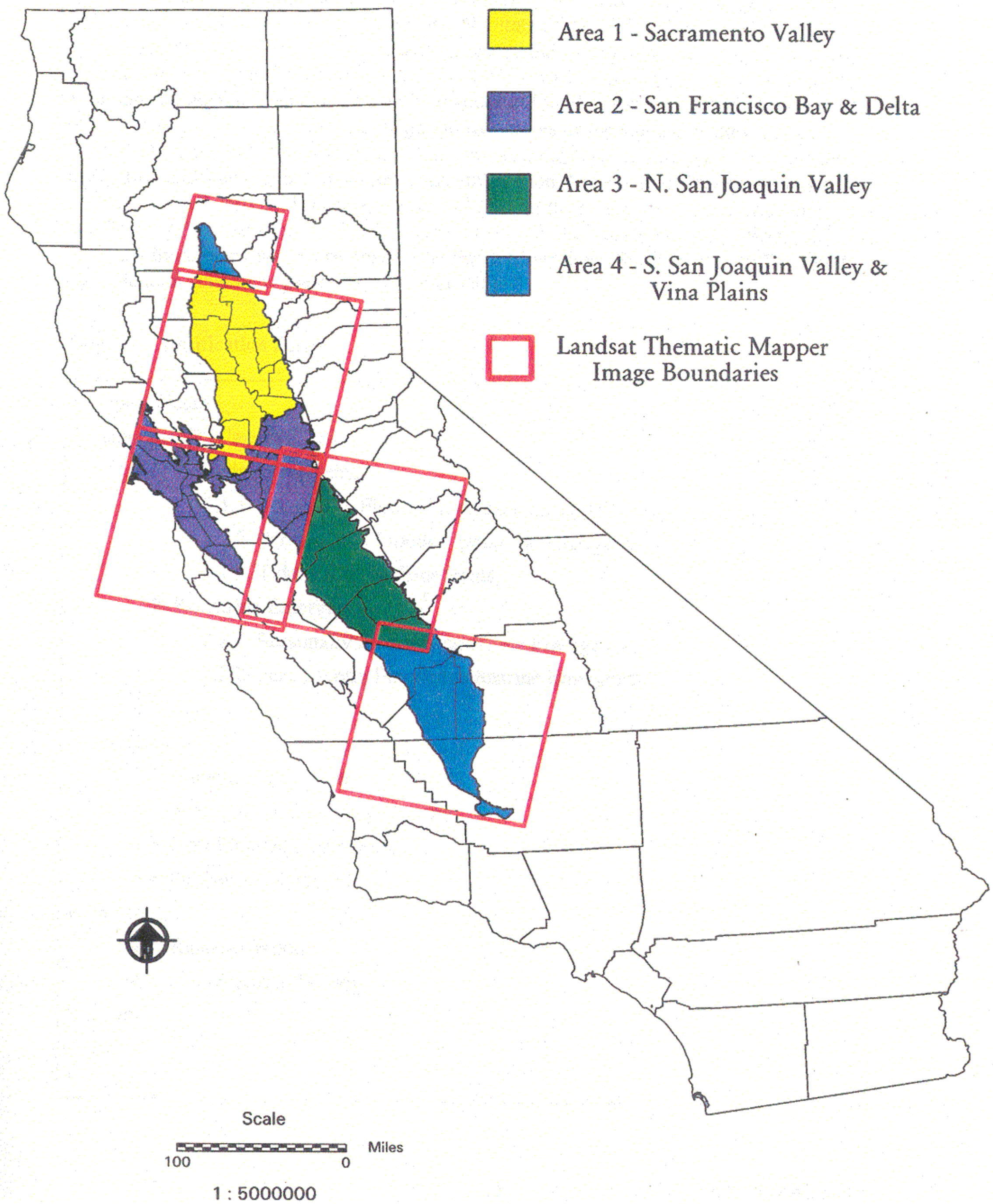
Figure 1. Project Design Flow Diagram.



9. PROJECT AREA

The Wetlands and Riparian GIS project area, shown in Figure 2, includes the Central Valley from Red Bluff to Bakersfield as defined by the 300 foot elevation contour and the San Francisco Bay area as defined by the 200 foot elevation contour. These project boundaries were developed in part using Central Valley Habitat Joint Venture boundaries. The boundaries were modified slightly where the available satellite imagery fell slightly short of the contour line. For image processing, the CDFG project area was subdivided into three areas based on scene boundaries. In all, the area to be mapped covers over 16,000 square miles or over 10.3 million acres.

Figure 2. California Wetland and Riparian GIS Project Area



10. CLASSIFICATION SCHEME

The wetlands classification system for this project was modeled in part after a "Classification of Wetlands and Deepwater Habitats of the United States" (Cowardin et al., 1979). The Cowardin system was modified somewhat by condensing all inland wetlands (Lacustrine, Riverine, Palustrine) into a single freshwater wetlands category (Palustrine). A Riparian category was added for woody vegetation found in the river flood plains based on the classification system described in “Riparian Resources of the Central Valley and California Desert” (Warner and Hendrix, 1985). The non-wetlands classification system was derived from the National Oceanic and Atmospheric Administration Coastwatch Change Analysis Project (NOAA C-CAP) protocols (Dobson et al., 1995) and the results of a recent National Aeronautics and Space Administration Earth Observation Commercialization Program (NASA EOCAP) wetlands monitoring project performed by Pacific Meridian (Spell et. al., 1995). The final classification scheme is presented below in Table 2.

Table 2. Classification Scheme.

1. Open Water
2. Emergent Wetlands / Flats
    - 2.1 Estuarine Emergents
        - 2.1.1 Seasonally Flooded Estuarine Emergents
        - 2.1.2 Permanently Flooded Estuarine Emergents
        - 2.1.3 Tidal Estuarine Emergents
    - 2.2 Palustrine Emergents
        - 2.2.1 Seasonally Flooded Palustrine Emergents
        - 2.2.2 Permanently Flooded Palustrine Emergents
    - 2.3 Flats
3. Agriculture
    - 3.1 Flooded Agriculture
    - 3.2 Seasonally Flooded Agriculture
    - 3.3 Non-Flooded Agriculture
    - 3.4 Orchards / Vineyards
4. Woody
    - 4.1 Riparian Woody
    - 4.2 Non-Riparian Woody
5. Grass
6. Barren
7. Other

Considerable effort went into developing a classification scheme that would be mutually exclusive (each area falls into only one class) and exhaustive (covers all land covers in the project area). The challenge was to design a scheme that would be useful to potential wetland database users and could be derived from the use of two dates of satellite imagery. This classification structure was reviewed and approved by the Project Technical Advisory Team (See Appendix A).

Descriptions of each of the categories in the classification system are listed below.

1. Open Water - Open water features (both fresh and salt water) that were identified on the summer image only.

2.1.1 Seasonally Flooded Estuarine Emergents* - emergent vegetation identified as: a) dry (i.e. no flooding or moist soil) on the summer image, b) inundated on the winter image, and c) within areas classified as Estuarine by the National Wetlands Inventory. Examples of estuarine emergents are pickleweed and saltgrass. This class may include areas which are subject to freshwater runoff or managed by means of fresh water flooding and support brackish or freshwater habitats, such as areas of Suisun Marsh.

2.1.2 Permanently Flooded Estuarine Emergents* - wetland emergent vegetation identified as: a) flooded or having moist soil on the summer image and thus assumed to also be flooded or moist in the winter, and b) within areas classified as Estuarine by the National Wetlands Inventory. Examples of estuarine emergents are pickleweed and saltgrass. This class may include areas which are subject to freshwater runoff or managed by means of freshwater flooding and support brackish or freshwater habitats, such as areas of Suisun Marsh.

*Areas labeled as Estuarine which are managed for brackish or fresh water habitat can vary in seasonality of flooding and in geographic location and extent based on varying management schemes.

2.1.3 Tidal Estuarine Emergents - wetland emergent vegetation identified within areas classified as Tidal by the San Francisco Estuary Institute Baylands Atlas data and classified as Estuarine by the National Wetlands Inventory. Examples of tidal estuarine emergents are pickleweed and saltgrass.

2.2.1 Seasonally Flooded Palustrine Emergents** - emergent vegetation identified as: a) dry (i.e. no flooding or moist soil) on the summer image, b) inundated on the winter image, and c) within areas classified as Palustrine, Lacustrine, or Riverine by the National Wetlands Inventory or outside of any areas classified as Estuarine by the National Wetlands Inventory. This class includes areas that were managed as moist soil habitat for waterfowl. Typical vegetation includes swamp timothy, pricklegrass, and watergrass.

2.2.2 Permanently Flooded Palustrine Emergents** - wetland emergent vegetation identified as: a) flooded or having moist soil on the summer image and thus assumed to also be flooded or moist in the winter, and b) within areas classified as Palustrine, Lacustrine, or Riverine by the National Wetlands Inventory or outside of any areas classified as Estuarine by the National

Wetlands inventory. Typical vegetation in this class includes bulrushes and cattails. Managed wetlands where summer water was visible were included in this class.

> ** Managed areas labeled as seasonally or permanently flooded palustrine can vary in seasonality of flooding and geographic location and extent based on varying management schemes.

2.3 Flats - includes tidal flats, mud banks, and sand bars that were visible above the water level on the summer image.

3.1 Flooded Agriculture - Agricultural lands where standing water or very moist soil was present on both the winter and summer images. This includes immature rice fields where the rice plant was not yet fully emergent above the water on the summer image and were inundated on the winter image.

3.2 Seasonally Flooded Agriculture - Agricultural lands where standing water was present on the winter image and growing crops were present on the summer image. Mature rice fields and other crops with winter flooding regimes were included in this class.

3.3 Non-Flooded Agriculture - Agricultural lands with growing crops present in the summer and no flooding detected on either the summer or winter image. Row crops and other non-flooded agriculture were included in this class.

3.4 Orchards/Vineyards - Orchards include almonds, walnuts, and various fruits grown in the agricultural areas of the Central Valley and in the valleys north of the Bay area. Vineyards are included in this class.

4.1 Riparian Woody - areas dominated by woody scrub/shrub vegetation and trees that are located within a riparian mask based on proximity to selected hydrography features from the CDFG Rivers Assessment data, NWI data, Natural Diversity Data Base (NDDB), and a hand-digitized floodplain map. The parameters used to define the mask were tailored to reflect differences in riparian forest habitats in three ecological regions found within the project area. These parameters are discussed in detail in Section 8 of this report.

4.2 Non-riparian Woody - areas dominated by woody scrub/shrub vegetation and trees that were not included in the Riparian Woody class. Residential areas with significant tree cover are included in this class.

5. Grass - includes managed grasslands, such as pasture, golf courses, and schoolyards, and natural grasslands such as those found in the foothills.

6. Barren - exposed soil with little or no vegetation present. This class includes fallow or recently plowed fields. Some barren land may have been classified as Other.

7. Other - includes areas of urban and suburban development, industrial complexes, commercial centers, airport runways, and other areas dominated by structures and paved surfaces. Some areas of development may have been classified as Barren.

11. DATA

The datasets used in the project are discussed below:

Thematic Mapper Imagery

Ten Landsat Thematic Mapper (TM) scenes--a summer and winter scene from each of four scene locations covering the project area-- were acquired and processed to produce the Wetland and Riparian GIS database. TM imagery offers a number of advantages for this application. First, it provides the large regional coverage needed for a project of this scope. Second, the Landsat satellite offers repeatable and standardized data coverage. A given point on the earth is covered every 16 days by the Landsat satellite, providing data for repeat mapping and monitoring of resources. And third, TM's Band 5 (1.55-1.75 micrometers) is sensitive to both vegetation and soil moisture content and has proven useful for identifying both water and wetland features. Finally, it is a cost effective data source since one scene covers approximately eight million acres. At around $6,000 per scene, this is less than one cent per acre for purchase of both a summer and winter scene for each area. For this project, a total of ten scenes were purchased. An additional scene previously purchased by DU was also used.

Vegetation phenological cycles, soil moisture differences, and cultural land management practices can influence the type and extent of land cover classes that can be extracted from imagery collected at different times of the year. Thus it is important that these factors be considered in terms of meeting the goals of the project when selecting the dates of imagery to be used. After reviewing the dates and quality of available imagery and assessing the seasonal characteristics of the land cover and flooding in the project area, the scenes listed in Table 3 were selected for the project.

Table 3. Satellite Imagery Acquired for the Project.

Coverage Area	Scene Type	Path/Row	Date
Winter Season			
Sacramento Valley	Landsat TM	44/33	1/3/93
San Francisco Bay/Delta	Landsat TM	44/34	1/3/93
N. San Joaquin Valley	Landsat TM	43/34	11/9/86
N. San Joaquin Valley	SPOT	533/275	11/13/90
S. San Joaquin Valley	TM	42/35	12/20/92
Vina Plains	TM	44/32 Quad 3	1/3/93
Summer Season			
Sacramento Valley	Landsat TM	44/33	6/28/93
San Francisco Bay/Delta	Landsat TM	44/34	6/28/93
N. San Joaquin Valley	Landsat TM	43/34	7/7/93
S. San Joaquin Valley	Landsat TM	42/35	6/30/93
Vina Plains	Landsat TM	44/32 Quad 3	6/28/93

An attempt was made to acquire cloud-free imagery from similar dates for all regions. However, the only available 1992/1993 TM winter scene for the North San Joaquin Valley had significant cloud cover over portions of the project area. Furthermore, no cloud-free TM scenes were available from the winter of 1993/1994 or 1994/1995. A scene search of imagery from other sensors was conducted and a SPOT scene from November 13, 1990 was selected as the nearest-date acceptable winter scene. SPOT has a pixel resolution of 20 meters, smaller area coverage than a TM image, and four bands of data (three visible and one near-infrared) compared to the seven TM bands. While the selected SPOT scene covered the Grasslands, the largest concentration of wetlands in the Northern San Joaquin Valley, it did not provide full coverage of the Northern San Joaquin project area. Thus, a TM scene from November 9, 1986 was used in areas not covered by the SPOT scene.

All of the imagery was terrain corrected and projected to UTM Zone 10 by the image distributor except the SPOT scene which was registered to the terrain corrected TM scenes. For the terrain correction, each image was rectified using both ground control points and a digital elevation model to correct for distortion caused by elevation differences in the image. The TM imagery had a resolution of 30 meter pixels, while the SPOT image had a resolution of 20 meter pixels. The project area included portions in UTM zone 10 and zone 11, but for the purpose of digital processing and display, all of the imagery was projected to zone 10 which contained the majority of the project area. This enabled the imagery and classified map data from throughout the project area to be displayed as a single, contiguous data layer.

Project Boundaries - The Central Valley portion of the project area was defined by the 300 foot elevation contour. The San Francisco Bay region included areas beneath 200 feet in elevation. These contour intervals were digitized from 1:250,000 scale USGS quads and used to subset the imagery to the project area.

National Wetlands Inventory - The National Wetland Inventory is a U.S. Fish and Wildlife Service mapping program that produces detailed wetland maps by manual interpretation of aerial photographs. In this project, NWI data were used for masking the imagery, GIS modeling, and for developing summary wetland statistics for the South Coast region.

CDFG River Reach Hydrography coverage - USGS 1:100,000 scale Digital Line Graphs (DLG's) supplied by CDFG were used to build a buffer around perennial streams for modeling the riparian woody class.

Department of Conservation Farmlands Mapping and Monitoring Program data - GIS data layers from the Department of Conservation Farmlands Mapping Program were used to assist in separating agriculture from spectrally similar emergent wetlands and uplands. These data layers are produced on a repeat cycle for individual counties by interpretation of 1:130,000 scale aerial photography. The data were acquired in Intergraph format and converted ARC/Info coverage format using Arc Macro Language (AML). Appendix B shows the coverage of the Farmlands Mapping data used in the project. For areas not covered by the Farmlands Mapping data, heads-up digitizing was performed over the summer TM image to delineate agricultural areas based on the best hardcopy data or photos available.

Natural Diversity Data Base - The Natural Heritage Division's Natural Diversity Data Base is an inventory of recorded occurrences of rare and endangered plant and animal species and natural communities. From this data base, a polygon coverage of riparian communities along the Sacramento River was extracted and used along with other ancillary data layers to model the riparian woody class.

San Francisco Estuary Institute Baylands Atlas Data - The Baylands Atlas is based on the National Wetlands Inventory data for the San Francisco Bay area with modifications and corrections resulting from a review process by local representatives of state and federal agencies. This data was used for GIS modeling to assign a secondary wetland label distinguishing tidal from diked wetlands.

Metadata for these datasets and all others used in this project are included in Appendix B.

12. METHODS

Reference Data Collection

Ideally, for a land cover mapping project, detailed, quantitative field data, such as species composition, percent cover, and soil moisture, is collected at a large number of field sites randomly scattered throughout the project area. However, because much of the land in the Central Valley is privately held, access was limited to what could be viewed from public roads. Also, the seasonal variability of many of the land covers made it impossible to collect information that accurately reflected conditions observed in both the summer and winter dates of imagery. Therefore, most of the collected field data was qualitative in nature. Field notes consisted of a single class label from the classification scheme for each site which indicated dominant habitat and, where appropriate, the inferred inundation of the site in the winter, such as "Seasonally Flooded Emergents" or "Seasonally Flooded Agriculture".

In addition to field notes taken during visits to sites, notes were made on field maps by Pacific Meridian Resources staff during flights with CDFG staff in the CDFG aircraft over Sacramento Valley, Suisun Marsh, and northern San Joaquin Valley in May and June of 1995. These flights were invaluable in that they allowed the analyst to cover large areas which had been inaccessible on the ground. The flights also enabled the analyst to see the land cover from a birds-eye view as the satellite "sees" it.

The field data, collected both on the ground and from the air, was supplemented by reference data obtained from refuge managers, Department of Water Resources land use data, and aerial photography. An extensive search for aerial photography revealed little in the way of current photography. The most recent available photographs were National Aerial Photography Program (NAPP) color-infrared aerial photographs collected in the late 1980's. A total of 292 of these 1:40,000 scale aerial photographs were purchased from USGS EROS Data Center to assist the analyst in classifying the satellite imagery. Appendix C lists the NAPP aerial photographs that were purchased.

Hardware/Software

An HP 9000 Series 700 Model 715 workstation was purchased for the project with the following configuration:

HP 9000 Series 700 Model 715 Workstation with 75 Mhz CPU, 96 Mb RAM, and HP-UX 9.0.3.

20" Color Monitor with CRX24 Graphics

660 Mb SCSI CDROM Internal Drive

2 - 1 GB SCSI II Disks

2 - 2 GB SCSI II Disks

DDS DAT tape drive (4mm)

The primary software used for the project was ERDAS IMAGINE 8.2 and ARC/Info 7.03. This software was provided by CDFG. CLUSTAR and GRAPHER software were used for signature analysis. Plots were produced on a Calcomp 58436 color electrostatic plotter, an HP Designjet 650C plotter , and an HP Deskjet 1200C.

Preprocessing

Each satellite image was downloaded from tape and checked for both overall quality and registration with overlapping images. To improve discrimination of landcover features, the thermal band was removed from the TM images and replaced with a red/near-infrared ratio band generated by dividing TM band 3 by TM band 4 values at each pixel location. The thermal band, which has a coarser spatial resolution (120 meter) than the other TM bands, often contributes little to a landcover classification and may even introduce confusion. A red/near-infrared ratio band in contrast may highlight subtle vegetation and soil moisture differences not evident in any single band due to the different reflectance characteristics exhibited by these features in both band 3 and band 4 (Tucker, 1979). A red/near-infrared ratio band was also added to the SPOT image using SPOT bands 2 and 3.

After the quality check and band selection was completed, the images were subset to the project area. Images collected on the same date and in the same orbit path generally have similar radiometric properties and therefore can be mosaicked and processed together. Thus, the two summer TM scenes from Path 44 were stitched together (mosaicked) and subset with the project boundary coverage. After this initial subsetting, the mosaicked image was further subset along a Central Valley Habitat Joint Venture basin boundary to produce two smaller images of more manageable size--the Area 1 and Area 2 summer image subsets. The same was done with the Area 1 and Area 2 winter images. The Area 3 and Area 4 TM scenes, which were from a different path than the Area 1 and 2 scenes, and the Area 3 winter SPOT scene were each subset separately using the project boundary coverage. The TM scenes used for the Vina Plains region of Area 4 were also subset separately. The resulting processing areas are shown in Figure 2. Each subset image was then processed individually to produce the final classified map. In retrospect, the division between Area 1 and 2 should have been based on ecological features rather than political boundaries that have little correspondence to land cover.

Image Stratification

Before beginning the image classification process, the summer image for each project area was stratified into 3 general land cover categories: 1) wetlands, 2) agriculture, and 3) uplands (defined here as non-wetlands and non-agriculture). The purpose of the image stratification is to separate spectrally similar classes such as emergent rice and emergent wetlands and to refine the spectral signatures as much as possible. To stratify the imagery, a master mask was created for each project area using two ancillary GIS datasets and the classified winter TM imagery. The first data layer used in the mask consisted of wetlands from the digital NWI data. This layer was created by appending the NWI quads, converting them to raster format (30 meter pixels), and registering the raster file with the imagery. The same was done with the Department of Conservation's Farmlands Mapping and Monitoring county coverages to produce an agricultural mask as the second data layer. The third data layer, known as the Winter Wet layer, was added to reduce errors caused by NWI wetland omissions. This layer was created by classifying the winter TM imagery to identify areas of winter inundation (i.e. potential wetlands).

To create the master mask, the individual data layers were weighted and overlaid. The weighting gave NWI wetlands dominance over the agricultural mask to ensure that all previously identified wetland areas were included in the wetlands strata. The agricultural mask was given dominance over Winter Wet to prevent flooded agricultural fields from inclusion in the wetlands strata as potential wetlands. This process is diagrammed in Figure 3. Once completed, the master mask was used to mask out or stratify the summer imagery to produce three imagery files consisting of potential wetlands, agricultural lands, or uplands respectively as shown in Figure 4. Each image strata was then classified independently.

Figure 3. Process to Create Mask for Stratifying Imagery

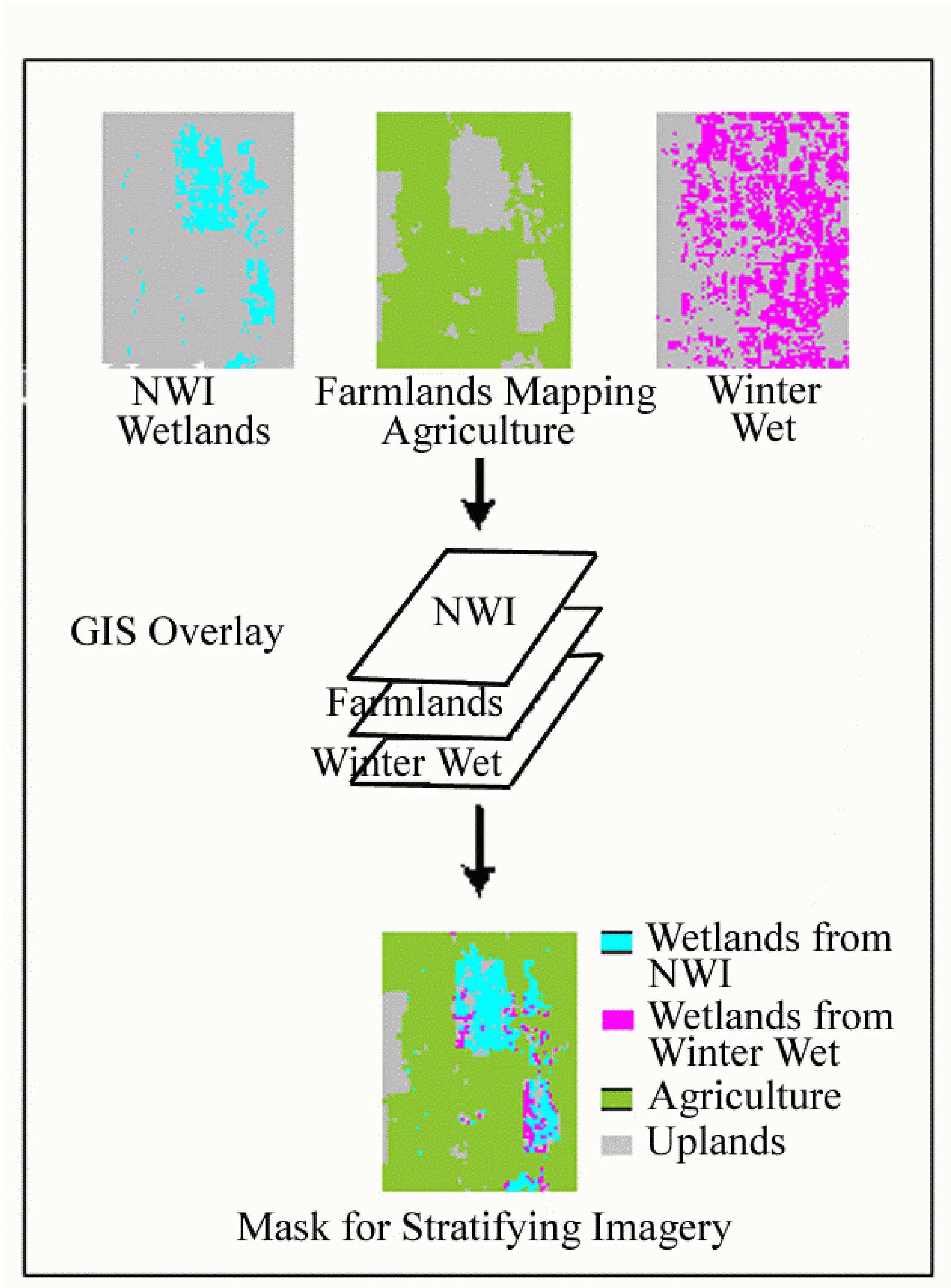
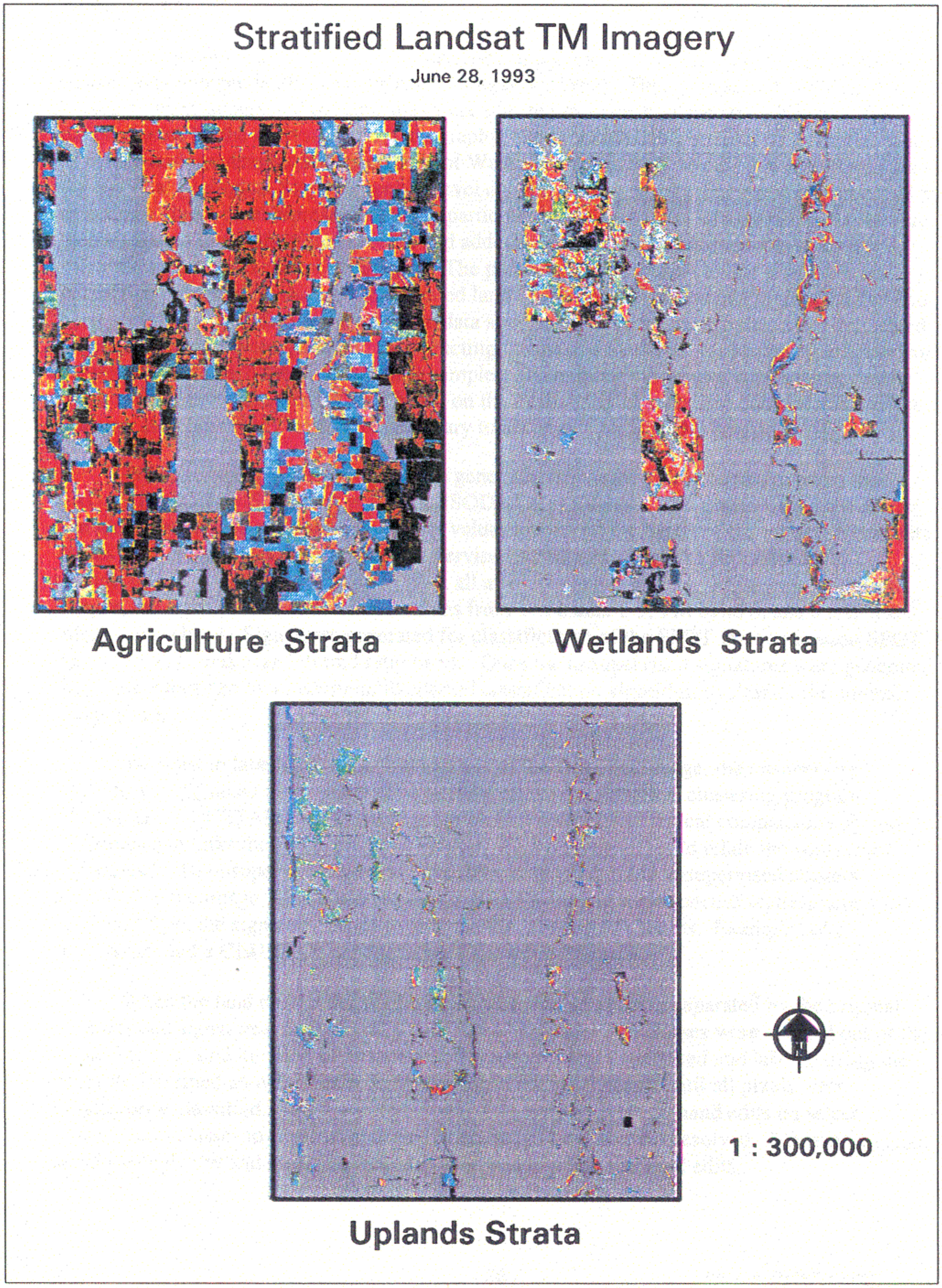


Figure 4. Results of Image Stratification



Classification

A combined supervised and unsupervised approach was used to classify each of the five image strata independently (Chuvieco and Congalton, 1988). This process is diagrammed in Figure 5. First, supervised training sites were selected from each image strata based on field data collected by the analyst, aerial photography, and other available sources of information such as refuge management plans, Department of Water Resources landuse data and a draft version of the National Biological Survey's species level data for Suisun marsh. Each site was "seeded" by selecting a single pixel representative of a particular land cover class. Neighboring pixels were then evaluated in an automated process and added to the training site if they met analyst specified spectral and spatial parameters. The parameters were varied by the analyst in an interactive process until the seed represented land cover patterns or features in the data that had been previously identified from reference data sources. Once the training sites were delineated , spectral signatures were generated by extracting the mean data values for each band of data from the pixels within each "seed" or training sample. The number of training samples from each strata varied (anywhere from 20-60) based on the availability of reference data and the analyst's decision as to how many sites were necessary to accurately classify the imagery.

Next, unsupervised signatures were generated from each stratified image using the ERDAS IMAGINE ISODATA program. ISODATA evaluates all the pixels within the image and identifies statistical clusterings of data values among all the bands of the image. Mean data values from the clusters serve as the unsupervised signatures. Both the supervised and unsupervised signatures were derived from all available bands of data. In the case of the TM images, the signatures included mean values from TM bands 1-5, TM band 6, and a red/near-infrared ratio band. Signatures generated for classification of the SPOT image included SPOT bands 1-3 and a red/near-infrared ratio band. Once the unsupervised signatures were generated, they were submitted to a maximum likelihood classification algorithm to classify the summer image strata.

To assist in labeling the spectral clusters of the classified image, the unsupervised signatures were linked to the supervised signatures using a statistical clustering program, CLUSTAR. CLUSTAR is a PC based program that performs statistical comparisons of spectral signatures and links those that are most similar. This linking serves to relate the supervised signatures to the unsupervised spectral signatures to help label the unsupervised clusters identified in the image. In addition to the CLUSTAR output, multispectral scattergrams were generated from the signature means to assist in the labeling of clusters. Examples of a scattergram and a CLUSTAR dendogram are shown in Figure 6.

When the land cover classes of interest were not adequately separated by the original unsupervised signatures, the spectrally "confused" unsupervised classes were masked out of the image and a second iteration of unsupervised signatures were generated and labeled using the methods described above. This process was repeated as necessary until all pixels were satisfactorily classified. In a few cases, it was necessary to perform hand edits on select unsupervised classes to separate classes that could not be spectrally resolved. Information from aerial photography and other data sources was used to guide the hand edits.

Mosaicking the Strata

Once the classification was completed for each of the strata, the classified strata were mosaicked together to produce a continuous classified image of the whole project area.

Figure 5. Flow Diagram of Image Classification Used for Each Strata.

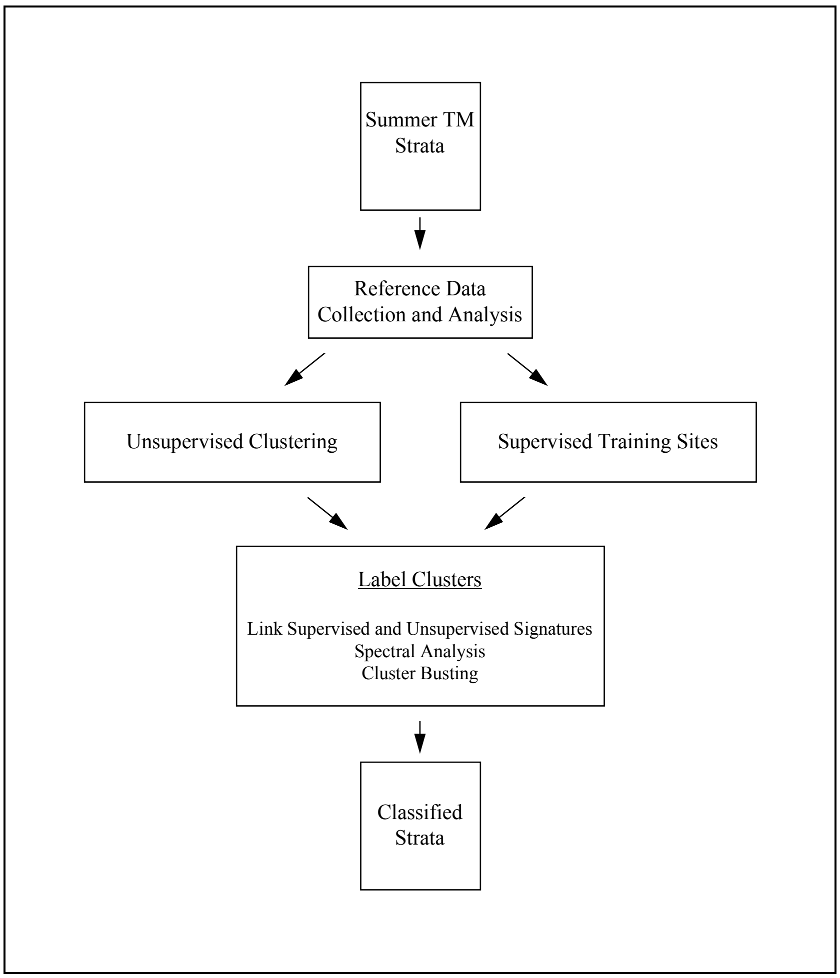
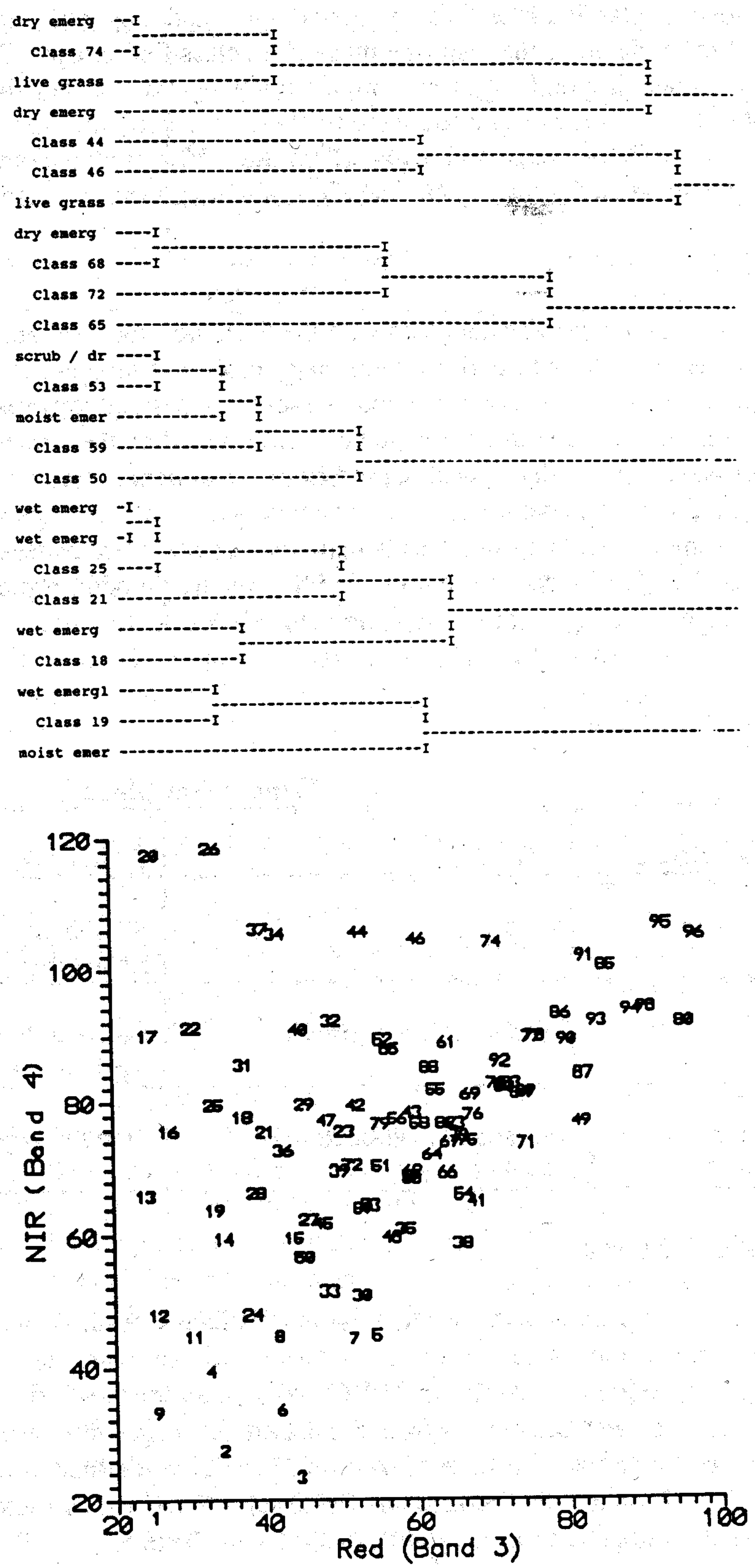


Figure 6. Examples of a Multispectral Scattergram and a CLUSTAR Dendogram.



GIS Modeling

After the spectral classification was completed, GIS modeling with ancillary data was performed to add further detail to the resulting mosaicked classified image. Three modeling processes were run in which specific classes from the multispectral classification were overlaid with ancillary data. Pixels in the output file were relabeled based on the combination of input values from both the classified image and the ancillary data. The modeled output was then stitched back into the classified image. The three GIS modeling processes are described below.

Winter Wet Modeling

The winter wet data layer was analyzed with the Wetland Emergent and Grass classes from the classified wetlands strata to derive a Seasonally Flooded Emergent class. For this project, the seasonally flooded emergent wetland classes were defined as wetland emergents that were not flooded or moist on the summer image but were flooded on the winter image. During the modeling process, each pixel that was classified from the wetlands strata as an emergent wetland or grass and that was also classified as inundated on the winter image was relabeled as Seasonally Flooded Emergent. The same was done with the agriculture classes from the classified agriculture strata to identify Flooded Agriculture and Seasonally Flooded Agriculture. The matrix of input classes and the resulting output classes are shown in Table 4.

Table 4. Winter Wet Modeling.

	Winter Wet Mask	
Classified Summer Strata	*Winter Dry*	*Winter Wet*
Dry Emergents / Grass	Grass	Seasonally Flooded Emergents
Agriculture	Non-Flooded Agriculture	Seasonally Flooded Agriculture
Flooded Agriculture	Seasonally Flooded Agriculture	Flooded Agriculture

Estuarine vs. Palustrine Modeling

A similar modeling process was used to reassign all pixels classified as emergent wetlands to either estuarine or palustrine classes. Because estuarine and palustrine vegetation is spectrally similar, it was necessary to incorporate digital NWI data to apply the Cowardin system level labels to the wetland classes. The wetland classes from the classified image were overlaid with the NWI data that had been recoded to two classes, estuarine and palustrine (defined as any non-estuarine area). This allowed the Permanently Flooded and Seasonally Flooded Emergent classes to be separated into estuarine and palustrine categories as shown in Table 5.

Table 5. Wetland System Modeling.

Table 5. Wetland System Modeling.

	NWI Mask	
Classified Landcover	*Estuarine*	*Palustrine*
Seasonally Flooded Emergents	Seasonally Flooded Estuarine Emergents	Seasonally Flooded Palustrine Emergents
Permanently Flooded Emergents	Permanently Flooded Estuarine Emergents	Permanently Flooded Palustrine Emergents

Riparian Woody Modeling

In order to separate spectrally similar riparian woody and non-riparian woody vegetation, a GIS model was applied in which riparian woody was defined as any areas that were identified as woody in the multispectral classification which also fell within a buffer around selected hydrographic features. Initially, the riparian class shown on the draft maps was modeled using a 90 meter (3 pixel) buffer around perennial streams, intermittent streams, rivers, and shorelines from CDFG's River Reach hydrography data layer. However, based on input from draft map reviewers, this model was modified to reflect differences in riparian forest habitats in three ecological regions.

1. Central Valley Region - A digital riparian natural communities map derived from the CDFG Natural Diversity data Base (NDDB) was used as a mask for riparian modeling along the Sacramento River. For other major rivers, such as the Feather, American, San Joaquin, Cosumnes, Mokelumne, and Stanislaus, a generalized floodplain mask was digitized on the screen using the oxbows and other features visible on the TM image as guides. For the remaining smaller streams in the Central Valley, the 90 meter (3 pixel) buffer was retained as a mask to model the woody riparian class.

2. Foothills Region - In the foothills region, riparian vegetation does not appear to occur frequently enough to warrant a buffer of all streams. Many stream areas, while supporting woody vegetation, do not necessarily support riparian vegetation. A buffer of all streams in the foothills region would tend to result in commission errors, over-representing the occurrence of woody riparian vegetation. Instead, NWI palustrine forest and scrub/shrub classes (where available) were used as a mask to model the riparian woody class in the foothills region of the project area and in the Sutter Buttes.

3. Coastal Region - In coastal regions of the project area, riparian vegetation often grows in narrow canyons which abut wooded areas of non-riparian vegetation. Because the coastal environment can be more hospitable to growth of riparian vegetation along stream courses, a narrow buffer of 30 meters (1 pixel) around selected hydrographic features was used as a mask within which woody vegetation was classified as riparian. The selected hydrographic features included rivers (right and left banks), and perennial and

intermittent streams. In addition to using this buffer, the palustrine forest and scrub/shrub classes from NWI were used, where available, as a complementary mask to define any previously mapped riparian corridors of greater width.

The three regions were defined using a digital data layer of the Jepson Bioregions as shown in Figure 7.

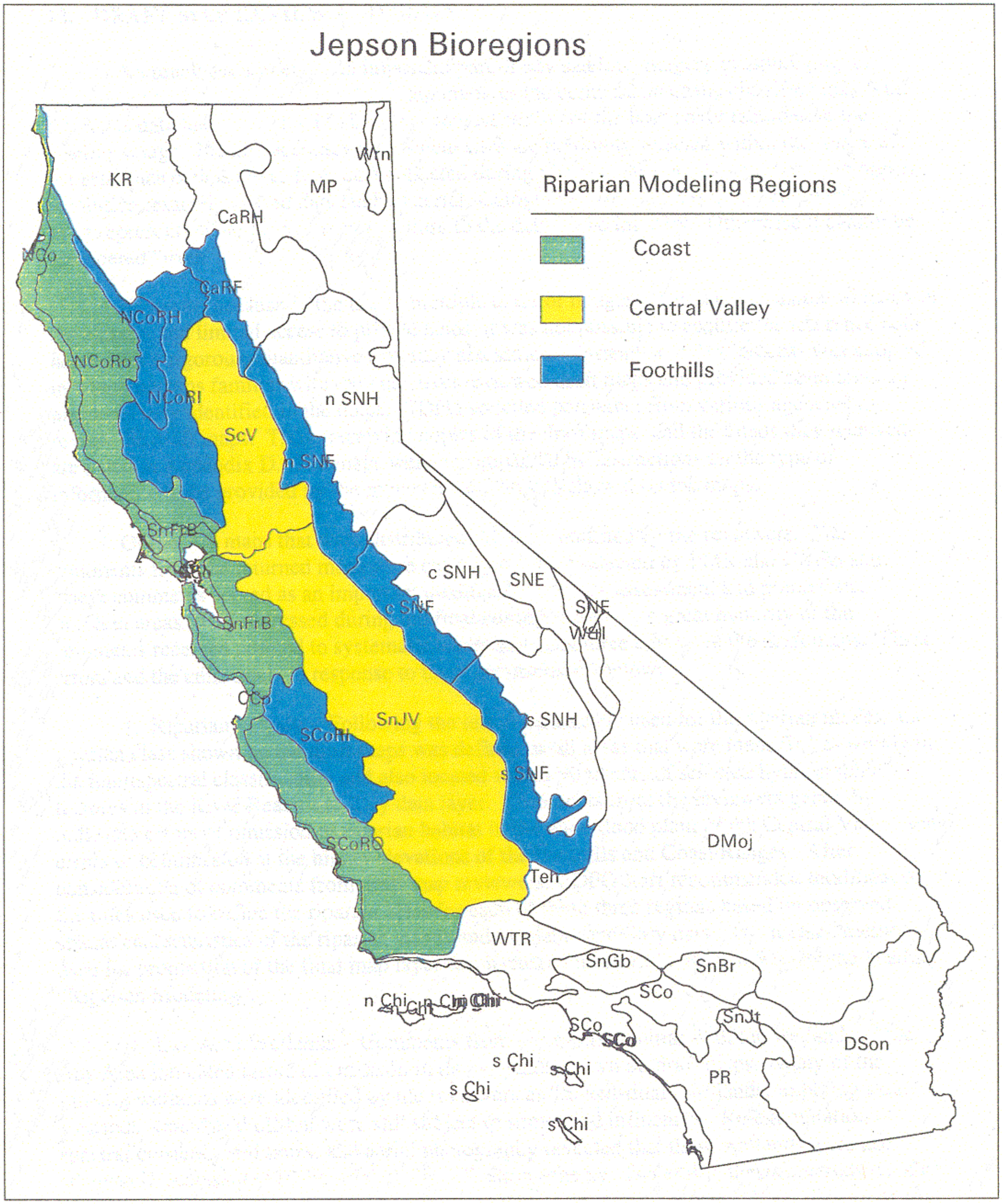


Figure 7. Jepson Bioregions Used for Riparian Modeling.

13. DRAFT MAP REVIEW AND EDITS

Accuracy assessment is an important part of any satellite imagery mapping project. Assessing the accuracy of a classified map involves the comparison of the classified map with reference data that is assumed to be a true representation of the land cover recorded in the satellite image. Ideally, accuracy assessment sites are randomly selected within the image and the reference data is either field data collected during visits to sites or sites identified on higher resolution remotely sensed data such as aerial photography. In each case, the reference data must represent the landcover as it was close to the date of the imagery. Otherwise it cannot be considered “truth”.

However, because of the use of multiple dates of imagery, the seasonal nature of many of the classes, and limited access to private lands, it was not possible to acquire the reference data needed for a rigorous, quantitative accuracy assessment. Instead, a review process was adopted in which persons familiar with the landcover reviewed draft maps and provided comments on problems they identified in the maps. CDFG solicited personnel from various agencies to review the draft maps. Those receiving copies of the draft maps, and the quads they received, are listed in Appendix D. The maps were accompanied by instructions on the type of information to be provided by the reviewers and how to show it on the maps.

Of the 108 maps that were distributed, 51 were returned by the reviewers. The comments from the returned maps were catalogued and evaluated by PMR and CDFG staff. These comments served as an important qualitative accuracy assessment and pointed out problem areas to be addressed during the final editing phase. The great majority of the comments received pointed to systematic errors affecting three classes in the draft maps. These errors and the edits made in response to them are discussed below:

1. Riparian Woody - Following the initial parameters used for the riparian model, the riparian class shown on the draft maps was defined as all areas that were identified as woody in the multispectral classification and also located within 90 meters of selected hydrographic features in the River Reach ancillary data layer. Comments from the reviewers generally indicated errors of omission of riparian habitat in the wide flood plain of the Central Valley and errors of commission at the higher elevations of the Foothills and Coast Ranges. After consideration of comments from draft map reviewers, CDFG staff recommended modification of the rules used to define the riparian class for each of these three regions based on observed spatial characteristics of the riparian stands and available ancillary data. The revised methods used for production of the final map layer are discussed in detail in Section 9 under the heading “Riparian Modeling”.

2. Bay Area Wetlands - Comments from reviewers familiar with the wetlands of the Bay Area indicated errors of omission in the wetlands shown on draft maps. Many of the missing wetlands were identified by the reviewers as “muted-tidal” wetlands, implying these wetlands were diked off but were still subject to some tidal influences. Re-examination of spectral clusters, field notes, and aerial photography revealed that these wetlands were not adequately represented in the original classification scheme. Generally, these wetlands were not “wet”

enough on the summer image to be classified as permanently flooded, yet they were also not fully inundated in the winter and therefore were not included in the seasonally flooded emergent classification. Instead, by default these wetlands were included in the upland grass class. To correct this omission, the classification scheme was modified by expanding the Permanently Flooded Emergent class definition to include these previously missing wetlands. The spectral clusters of the Area 2 wetlands strata were then re-evaluated using the modified wetland class definitions and re-labeled where required.

3. Seasonally Flooded Agriculture - Another consistent comment received from the reviewers was one suggesting overclassification of Seasonally Flooded Agriculture in the Delta and northern San Joaquin Valley, both part of the Area 2 processing unit. This error would result from an overclassification of inundated land on the winter image. To address this, the spectral threshold used to separate flooded or inundated lands from non-flooded lands was re-evaluated and modified using reviewers comments and comparison with the spectral threshold used for the Area 1 processing unit. In this way, the winter wet mask used to define the Seasonally Flooded Agriculture class was reduced in total area, resulting in a corresponding reduction in potential commission errors in this class.

The remaining comments from the reviewers pointed out minor, non-systematic errors that were best addressed with site-specific hand edits. These comments were few in number and in several cases were not included in the edits because they called for class labels based on land use that was not represented in the classification scheme or that was not supported by the ancillary data used for GIS modeling.

14. USER NOTES

As with any map, it is important for users to clearly understand the data sources used to construct the map and potential sources of error to ensure appropriate use of information represented. For this project, the primary data source used was satellite imagery. Landsat Thematic Mapper imagery from two seasons (summer and winter) and a SPOT scene were processed to produce the final classified map for the project area. Satellite imagery is in a sense a "snapshot" of the earth, recording the spectral characteristics of the land cover at a specific moment in time. Therefore, a map produced from a satellite image also reflects the land cover at that specific time only. This is important to keep in mind when using the information in the final map.

The "snapshot" characteristic has particular implications for classes in the map that were derived based on the presence or absence of standing water on the winter image. Winter flooding is a management practice used in production of certain crops and moist-soil habitat for waterfowl. However, the time and duration of this winter flooding may vary and thus water may or may not be recorded on a specific winter image. Also, the water that is identified on a winter image could reflect a recent precipitation event rather than a management practice. Thus, there may be errors of omission where an agriculture field or wetland was not flooded on the winter image used and therefore was classified as non-flooded agriculture. Likewise there may be errors of commission where the land was temporarily inundated, perhaps due to precipitation, and therefore resulted in a misclassification as seasonally flooded agriculture or seasonal wetlands. Area 3, in particular, may have errors of this nature since the winter image was from a different year than the summer image and may reflect different land management practices. Thus, it is important to remember that the emergent wetlands and agriculture classes can vary in location and in seasonality of flooding based on varying management schemes and variations in seasonal precipitation.

A second factor the user should be aware of is the resolution of the imagery used to produce the map. The Thematic Mapper imagery used for this project had a resolution of 30 meters. In other words, each pixel represents 30 meters squared (0.22239 acres/pixel) on the ground. Because of this, some small or narrow features may not have been distinguished and therefore may not be represented on the map. Narrow streams or roads in particular may not show up or may be discontinuous. Generally, 2 acres is considered the smallest feature size that can reliably be mapped using TM imagery.

The resolution of the imagery also may affect the classification when two or more land covers are present within a single pixel. In some cases, no single land cover is dominant and therefore the spectral characteristics of the pixel do not strongly resemble any of the constituent land covers. These pixels, known as “mixed pixels”, are difficult to classify and sometimes result in a class label that is unrelated to any of the constituent land covers. An example of this is often found along the edges of rivers where the mixture of water and upland vegetation in a pixel may result in its being classified as wetland emergents. This type of error is common in a map produced by satellite imagery but is usually confined to single, scattered pixels and therefore contributes little error in terms of percentage of the total acreage.

Along with the satellite imagery, a number of ancillary data layers were incorporated into the processing to produce the Wetlands Inventory. While previous experience has shown that the use of NWI and Farmlands Mapping data improved classification results greatly, these data sets may have introduced error of their own. For example, the NWI data was derived from aerial photography collected in the mid-1970s and mid-1980s and therefore may not include some recent wetland restoration projects. Also, the Farmlands Mapping data was incomplete in some areas. In both cases, steps were taken to overcome these potential sources of error, but some effects due to these sources of error may remain.

The riparian class also requires attention from the user. The riparian areas in the foothills were derived using only the NWI data as a mask. In the coastal regions of the project area, riparian areas were derived using a spatial proximity model in which any woody pixel falling within 30 meters of selected hydrography features, or within NWI palustrine classes was relabeled as riparian woody. In the valley, the best available riparian data, or floodplains were used along major rivers to relabel woody pixels as riparian woody, while smaller streams retained the 90 meter (3 pixel) buffer as a mask. As discussed earlier, this type of GIS modeling may result in errors of omission or commission.

Due to limitations inherent in the imagery and ancillary data employed in this project, accurate representation of riparian vegetation may not have been entirely achieved. In using the ancillary data and the modeling practices employed in this project, a concerted effort was made to minimize error while trying to provide the best possible representation of the location of riparian habitat or potential riparian habitat. The different modeling practices used in each area and the potential errors associated with them should be considered by users focusing on the riparian class for purposes of conservation planning, resource identification, and protection.

As discussed earlier, the goal of this project is to develop and provide information in the form of a Wetland and Riparian GIS database for the Central Valley, Bay, and Delta regions to support cooperative conservation planning and wetland resource protection efforts of state, federal, and local governments, and private organizations. Due to the scale and the scope of this mapping effort, the database will meet different needs with varying levels of success. Because of its large scope, the database will likely meet the needs of coarser level planning (planning efforts over a large area) with greater success than it will for finer level planning efforts, such as those occurring at the local level. For coarse level planning, the database provides information for the entire Central Valley that is relatively uniform in coverage, date, and scale, useful for statewide and regional level planning efforts. The benefits of covering a large area in a uniform manner may come at a cost in terms of accuracy in some cases. Over a large project area such as the Central Valley, it is not possible to consider all areas in great detail, and in some cases, local subtleties in cover or management may not be represented. Thus, for finer level planning, the database will likely best be used as a general baseline to focus gathering of more detailed information and to fill gaps until such information can be assimilated. In addition, effects of sources of error in the data also relate to the scale at which the information is used. Sources of error become increasingly significant as the information is used for finer levels of analysis. Classification errors which appear minimal at the state-wide or regional level may be significant when the data is used at a finer level. These issues of scale and accuracy require consideration by those who use the database for conservation planning and resource protection analysis.

15. FINAL PRODUCTS

The final products of this project include the original satellite imagery acquired for the project, the GIS data layer produced by classification of the satellite imagery, and the ancillary data sets acquired to assist in the classification process.

1. Wetlands and Riparian GIS data layer - This data layer consists of the final classified map for the whole project area in ERDAS IMAGINE (.img) raster format (30 meter pixels), UTM Zone 10, as produced by a combination of the classification of satellite imagery and GIS modeling. A plot of the final GIS data layer is shown in Figure 8.

2. Satellite Imagery - Includes five Landsat Thematic Mapper scenes collected during the 1993 summer months, four Landsat TM scenes collected during the previous winter (1992-93), a Landsat TM scene from 1986, and a SPOT scene from November 1990.

3. U.S. Fish and Wildlife Service National Wetlands Inventory Data - The NWI 1:24,000 scale digital quadrangles covering Areas 1-3 were appended and archived as an

ARC/INFO polygon coverage. The NWI data used for Area 4 was in the draft stage and is not included for delivery.

4. San Francisco Estuary Institute Baylands Atlas Data - Archived as an ARC/INFO polygon coverage.

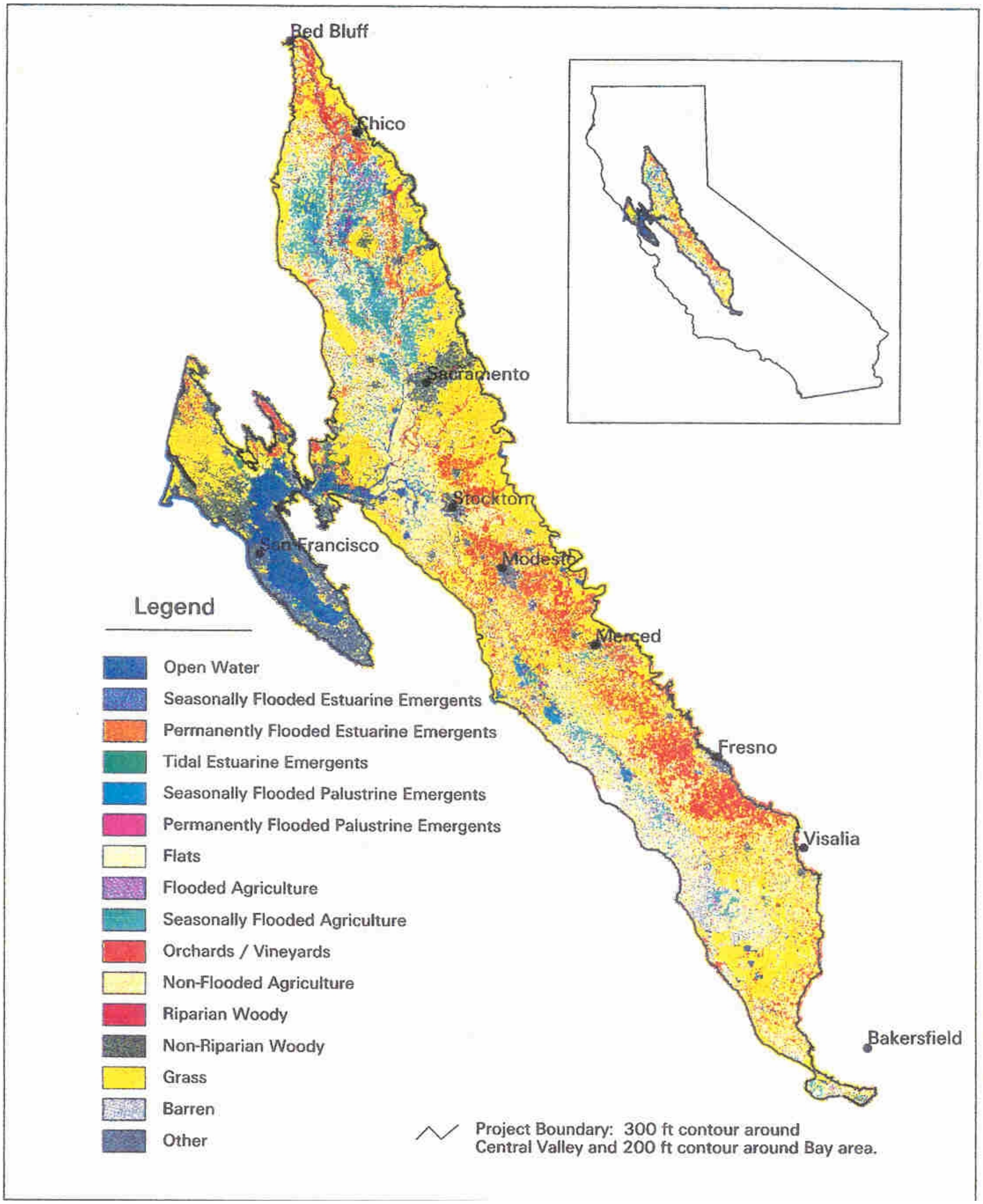
5. Department of Conservation Farmlands Mapping Data - Archived as ARC/INFO polygon coverages by county.

6. Project Boundaries - Archived as an ARC/INFO polygon coverage.

7. Aerial Photography - 192 CIR 1:40,000 scale aerial photographs selected from throughout the project area.

All of the data layers are projected in UTM Zone 10 and therefore will overlay each other. Detailed metadata for each GIS data layer is included in Appendix B. Aerial photographs are listed in Appendix C.

Figure 8. Wetlands and Riparian GIS - Classified Image.



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17. APPENDICES